W and Z Cross Sections at the Tevatron

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The CDF and D0 experiments at the Tevatron have used $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV to measure the cross section of W and Z boson production using several leptonic final states. An indirect measurement of the total W width has been extracted, and the lepton charge asymmetry in Drell-Yan production has been studied up to invariant masses of 600 GeV/c^2.

1 Introduction

The Tevatron collider has undergone a massive upgrade during the last five years. The construction of a new main injector with a recycler ring, and the improvements done to the antiproton source and booster ring promise an increase of instantaneous luminosity by an order of magnitude over Run I. The CDF and D0 experiments have also recently completed a major upgrade. CDF was refurbished with an entirely new tracking system, with up to 8 silicon layers providing precise measurement of track parameters close to the beam line, and with a new calorimeter for intermediate rapidities; the muon system has been extended to record tracks up to $|\eta| < 1.5$. D0 was endowed with a $2T$ axial field, and new silicon and fiber trackers; mini-drift tubes for forward muons and a new preshower have also been added.

The collider experiments have started recording $p\bar{p}$ interactions with their full functionality during 2002, and have used the physics-quality data collected till January 2003 to measure the production rate of W and Z bosons, which constitute the starting point for many high-P_T physics studies at the Tevatron, and are fundamental "standard candles" with which to understand and check detector performance.

2 W and Z Cross Sections

W and Z bosons are produced at the Tevatron through $q\bar{q}^{(\prime)}$ annihilation. The cleanest signatures involve high-P_T electrons or muons: $W \to e\nu$, $\mu\nu$, and $Z \to e^+e^-$, $\mu^+\mu^-$ all enjoy very small background contaminations. The $W \to \tau\nu$ decay can also be observed with clarity although backgrounds are much larger; other decays are hard to exploit or unobservable.

D0 and CDF presented their first W and Z cross section measurements at $\sqrt{s} = 1.96$ TeV in the summer 2002 [1]. Many of those results have now been updated using total integrated luminosities of $L = 72.0 \pm 4.3\ pb^{-1}$ (CDF) and $L = 31.8 \pm 3.2\ pb^{-1}$ (D0).

2.1 W Cross Section Measurements

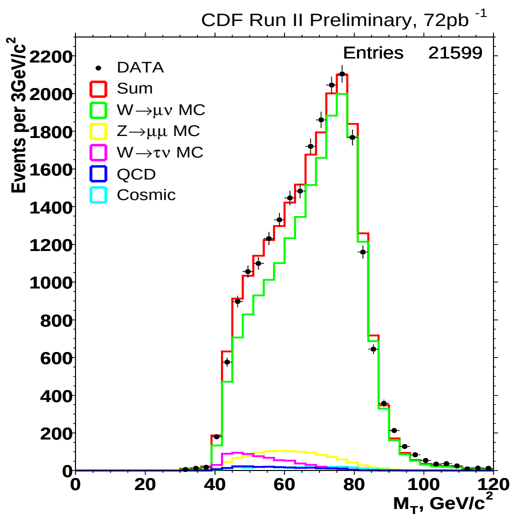

Figure 1: *Transverse mass distribution of $W \to \mu\nu$ candidates collected by the CDF II experiment in 72 pb^{-1} of Run II data.*

CDF collects $W \to e\nu$ decays with a trigger selecting high-E_T central electron candidates; after requiring one tight electron with $E_T > 25$ GeV matched to a track of $P_T > 10$ GeV/c and missing transverse energy $\not{E}_T > 25$ GeV, 38628 events are left in the data. The main background source is from QCD dijet events where a jet mimics the electron signal and large $\not{E}_T$ is due to a second poorly measured jet: using events with non-isolated electron candidates or small $\not{E}_T$, $1344 \pm 82 \pm 672$ events are estimated from that process. Additional backgrounds from $W \to \tau\nu$ decays (768 ± 22 events) or misidentified $Z \to ee$ decays (344 ± 17) are estimated from Monte Carlo simulations.

The acceptance is $A_{e\nu} = 23.4 \pm 0.05$ (stat.)± 0.70 (syst.)%; the systematic error is mainly due to the uncertainty in the parton distribution functions (PDF), that affect the fraction of decays yielding central electrons by 0.58%, and to the knowledge of the amount of material in the tracking volume (0.29%).

The result is $\sigma_W B(W \to e\nu) = 2.64 \pm 0.01$ (stat.) ± 0.09 (syst.) ± 0.16 (lum.)nb, in good agreement with NNLO calculations [2] ($2.731 \pm 0.002\ nb$).

CDF also measures $\sigma_W B(W \to \mu\nu)$. From central high-P_T muon triggers, events with a clean muon candidate are selected if the muon has $P_T > 20$ GeV/c and if $\not{E}_T > 20$ GeV. The transverse mass spectrum of the 21,599 W candidates is shown in Fig. 1. Backgrounds in this channel include cosmic rays, QCD processes, and misidentified boson decays ($Z \to \mu\mu$, $W \to \tau\nu$); their sum is estimated at 10.82 ± 0.18 (stat.) ± 0.96 (syst.)%. The total acceptance is $A_{\mu\nu} = 14.8 \pm 0.1$ (stat.) ± 0.5 (syst.)%; systematics are dominated by the uncertainty in the PDF (0.41%) and by the measurement of the W recoil (0.23%). The result is $\sigma_W B(\mu\nu) = 2.64 \pm 0.02$ (stat.)± 0.12 (syst.) ± 0.16 (lum.)nb, again in good agreement with NNLO calculations.

$W \to \tau\nu$ candidates can also be selected at CDF by collecting events with a $\not{E}_T > 25$ GeV hardware trigger at level 1, complemented by a subsequent software filter for τ identification at trigger level 3. Monojet candidates are kept if they have a single $E_T > 25$ GeV jet containing one $P_T > 4.5$ GeV/c charged track in a $10°$ cone and no other track within $30°$, and if $\not{E}_T > 25$ GeV; tight electron events from $W \to e\nu$ decay are explicitly removed. 2345 events pass the selection, with an estimated background of 612 ± 61 events mainly due to QCD processes. From those numbers CDF computes $\sigma_W B(\tau\nu) = 2.62 \pm 0.07$ (stat.) ± 0.21 (syst.) ± 0.16 (lum.)nb. Moreover, using the previously excluded $W \to e\nu$ signal in the same dataset, it is possible to

extract the ratio of coupling constants $G_\tau/G_e = 0.99 \pm 0.04$ (stat.) ± 0.07 (syst.).

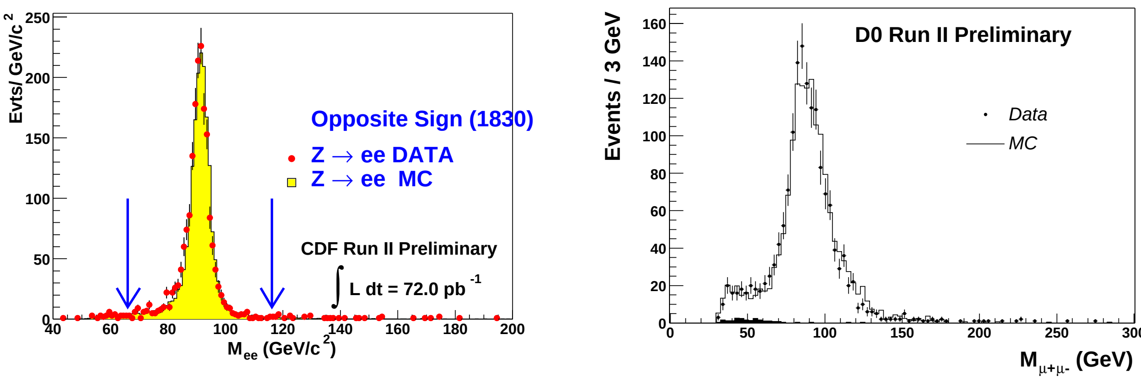

Figure 2: Left: invariant mass distribution of electron-positron pairs collected by CDF. Right: invariant mass distribution of $\mu^+\mu^-$ pairs collected by D0.

2.2 Z Cross Section Measurements

To select $Z \to ee$ candidates, CDF requires two central electrons with opposite charge, $E_T > 25$ GeV, and $P_T > 10$ GeV/c; they must have invariant mass in the $66 < M_{ee} < 116$ GeV/c^2 range. 1830 evts are thus collected (see Fig. 2, left), with 10 ± 5 estimated from background sources. The total acceptance is $A_{ee} = 11.49 \pm 0.07$ (stat.) ± 0.64 (syst.)%, where systematic errors are mostly due to PDF and modeling of tracker material. The cross section is measured at $\sigma_Z B(Z \to ee) = 267.0 \pm 6.3$ (stat.) ± 15.2 (syst.) ± 16.0 (lum.)pb, higher but consistent with the NNLO calculation [2] of 250.5 ± 3.8 pb.

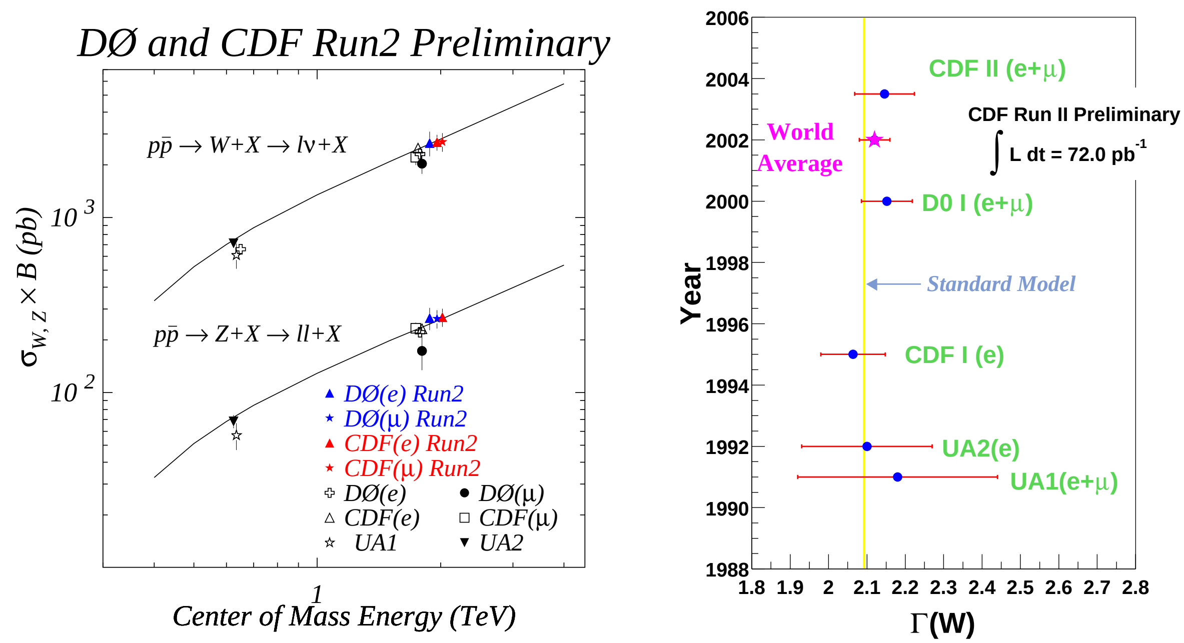

Figure 3: Left: comparison of cross section measurements for W and Z bosons with NNLO calculations (full lines). Right: comparison of the new CDF result on the W boson width with previous determinations.

Both CDF and D0 have updated their measurement of $\sigma_Z B(Z \to \mu\mu)$. From 1632 events containing two muon candidates with $P_T > 20$ GeV/c, CDF measures $\sigma_Z B(\mu\mu) = 246 \pm 6$

(stat.) ± 12 (syst.) ± 15 (lum.)pb. D0 bases the analysis on data collected between September 2002 and January 2003. 1585 events are selected by requiring two muon candidates of $P_T > 15$ GeV/c, separated in $\eta - \phi$ by more than $\Delta R_{\mu\mu} > 2.0$ (Fig. 2, right); the estimated background is $1.5 \pm 1.0\%$. The result is $\sigma_Z B(\mu\mu) = 263.8 \pm 6.6$ (stat.) ± 17.3 (syst.) ± 26.4 (lum.)pb.

3 Forward-Backward Dielectron Asymmetry

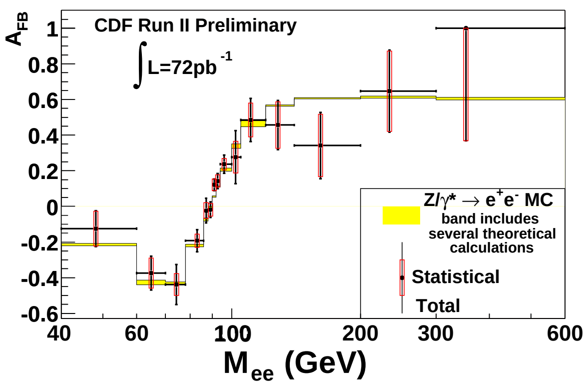

Figure 4: The forward-backward asymmetry of electron-positron pairs measured by CDF, compared to theory predictions.

CDF uses 5438 events with $40 < M_{ee} < 600$ GeV/c^2 from the $p\bar{p} \to Z(\gamma^*)X \to eeX$ process to measure the forward-backward charge asymmetry A_{FB} over a wide range of Q^2. Backgrounds are due to QCD processes and are estimated from same-sign or non-isolated electron-positron pairs; they amount to $N^{cc}_{QCD} = 21.5 \pm 5.9$ events for central-central pairs, and to $N^{cp}_{QCD} = 128 \pm 65$ events for events with one forward ($|\eta| < 2$) electron. The new A_{FB} measurement is shown in Fig. 4; results agree with theoretical predictions.

4 W/Z Ratio and W Width

Using the cross section measurements in the electron channel presented in Sec. 2, CDF computes the ratio $R_e = \sigma_W B(W \to e\nu)/\sigma_Z B(Z \to ee) = 9.88 \pm 0.24$ (stat.)± 0.47 (syst.), lower but consistent with NNLO predictions ($R_{th} = 10.66 \pm 0.05$) [2]. Using the LEP measurement of $B(Z \to ee)$ [3] plus theoretical predictions for σ_W/σ_Z and $B(W \to e\nu)$ [2], the measurement of R_e can be converted into an indirect determination of $\Gamma_W = 2.29 \pm 0.06$ (stat.) ± 0.10 (syst.) GeV, in good agreement to the most recent average of 2.118 ± 0.042 GeV [3].

In addition, using their muon decay results (Sec. 2), CDF finds $R_\mu = 10.69 \pm 0.27$ (stat.) ± 0.33 (syst.) and $\Gamma_W = 2.11 \pm 0.05$ (stat.) ± 0.07 (syst.) GeV. The electron and muon channel results can be combined into $\Gamma_W = 2146 \pm 78$ MeV. Fig. 3 compares that determination to previous measurements of the W boson width.

5 Concluding Remarks

W and Z cross sections in $p\bar{p}$ collisions have been shown to rise with s in accordance with NNLO calculations. The Drell-Yan asymmetry has been probed up to the invariant mass $M_{ee} = 600$ GeV/c^2. From the cross section measurements an indirect determination of the total width of the W boson has been extracted, in good agreement with Standard Model predictions. In conclusion, Run II at the Tevatron is starting to deliver: although the CDF and D0 detectors have not yet been exploited to their fullest potential, the results discussed here have already reached accuracy levels similar to Run I ones.

References

1. Pub. Proceedings 31st International Conference on High Energy Physics (ICHEP 2002), Amsterdam, The Netherlands, July 24-31, 2002. FERMILAB-CONF-02/256-E.
2. W.J. Stirling, private communication.

3. K. Hagiwara *et al.*, *Phys. Rev.* **D**66 (2002) 010001.